December 15, 2006

Kevin Stewart
Urban Drainage and Flood Control District
Suite 156-B
2480 West 26th Avenue
Denver, CO 80211

Re: ALERT Gaging System Maintenance Agreement 06-02.08, Final Report

Dear Kevin,

OneRain is pleased to present you with the accompanying ALERT Gaging System 2006 Final Report. The purpose of the Report is to summarize the ALERT system maintenance activities completed by OneRain in 2006 on behalf of the Urban Drainage and Flood Control District (UDFCD) under Agreement 06-02.08.

The accompanying Report includes a summary of the maintenance activities in 2006 and recommendations for future operation of the District's flood detection network. Since the network has steadily increased in size over the years and because there are increasing opportunities for multiple users of these data, OneRain and the District implemented new QA/QC techniques this year while reducing the number of scheduled maintenance visits. This reduced the overall cost of the contract while improving our ability to evaluate performance issues and proactively address them. Recommendations for the 2007 season are also included.

We have enjoyed this past year greatly, as we have the many preceding ones, and we look forward to our continued collaboration with the UDFCD. Please contact me with any questions.

Sincerely,

Jake Emerson, Field & Integration Services Director

cc: Ilse Gayl, Earl Weiler

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ALERT Gaging System Maintenance
Agreement 06-02.08

Annual Report
December 15, 2006

Presented To
Kevin Stewart
Urban Drainage and Flood Control District
Denver, Colorado

By

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EXECUTIVE SUMMARY

The purpose of this report is to summarize the ALERT system maintenance activities completed by OneRain in 2005 on behalf of the Urban Drainage and Flood Control District (UDFCD) under Agreement 06-02.08.

OneRain and the District conducted the 2006 maintenance operations quite differently from previous years. We reduced the number of site visits and increased the use of data-intensive quality assurance and quality control techniques. This report will discuss the effects of these changes. The results have been very positive.

Maintenance activities on the ALERT real-time monitoring network for 2006 have been completed. Table 1 outlines the maintenance activities for both the 2005 and 2006 operating seasons for the combined UDFCD/Boulder system.

Table 1: 2005 and 2006 Maintenance Service Statistics

Year	Total # of Maintenance Records	Total # of Service Calls	OneRain Service Calls	District Service Calls
2005	810	95 (11.8%)	75 (79%)	20 (21%)
2006	696	97 (13.9%)	83 (86%)	14 (14%)

The number of unscheduled service calls increased over previous years while the total number of service visits decreased by 14%. This is due to two factors: OneRain eliminated one of the five scheduled service rounds and there was a significant increase in the effort focused on data analysis. This close inspection of the transmitted data has set the conditions for OneRain to catch issues before they become problems. Also, we have been able to find problems that we would not have found without the newly developed tools.

Last season the unscheduled maintenance activities were dominated by pressure transducer (PT) and radio failures. These components faired much better this year. In 2006 OneRain spend more time on proactive battery replacement and tipping bucket rain gage maintenance. Using correlation analyses tools we were able to find gages that were under-reporting rainfall through comparison to neighboring gages. Unscheduled maintenance for PTs has tended to be the result of damage (District service calls) or sensor drift (OneRain service calls).

The following sites required the greatest number of unscheduled visits:

- Broadway (site 4580) 11 visits for program adjustment for Kim Elkins

- Green Ditch (site 4590) 4 visits for program adjustment for Kim Elkins
- James Creek (site 4440) 3 visits for PT replacement/calibration and one for investigation of RF issues.
- Sand Creek @ Colfax (site 860) 3 visits for power system
- Aurora Fire Station #12 (site 840) 3 visits for battery discharging
- Harvard Gulch Park (site 600) 3 visits for PT and sprinkler "contamination"
- Illiff Pond (site 650) 3 visits for PT and under-reporting rainfall

The 31 trips to these 7 sites accounted for 32% of all unscheduled service calls for 2006. There were seven trips attributed to the "District Service Call" category for potential tipping bucket issues. OneRain had simultaneously identified these issues, but gave credit to the District.

MAINTENANCE ACTIVITY SUMMARY

Site Additions

Four additional sites were added to the network in 2006: the Marshall Test Site rain gage in Superior, Sand Creek at Colfax rain and stage site, and the Broadway and Green Ditch sites in Boulder.

The Marshall site is located in the National Center for Atmospheric Research (NCAR) Marshall Test Site surrounded by other meteorological measurement stations. The site is located at N 39° 56' 57.21", W 105° 11' 43.38" (WGS84 datum). This site reports via the Blue Mountain repeater.

Figure 1: Marshall Rain Gage

The new rain and stage measurement station on Sand Creek at Colfax Ave was installed on a concrete drop structure on the north side of the Colfax bridge. The pressure transducer is housed in a well point screen buried in the sand. The site is located at N 39° 36' 15", W 104° 42' 59" (WGS84 datum). This site reports via the Smoky Hill repeater.

The Broadway site is located near the intersection of Broadway and Canyon Boulevard on Boulder Creek. The site is located at N 40° 00' 54", W 105° 16' 43" (WGS84 datum). This site reports via the Gold Hill repeater.

The Green Ditch site is on a distributary of Boulder Creek on the north-east side of the City. The site is located at N 40° 00' 54", W 105° 16' 43" (WGS84 datum). This site reports via the Gold Hill repeater.

Both the Broadway and Green Ditch sites were installed by OneRain for the City of Boulder Water Resources Department. Beyond flood detection they are used to measure water level (with flow measurements based on City rating curves) for compulsory water rights monitoring. These sites transmit hourly, with a change to transmit criteria of 0.1 foot.

Damaged Equipment and Site Reinstallations

The Upper Leyden rain gage site has been perpetually plagued by debris. This site has needed cleaning on nearly every maintenance round due to bird waste; primarily from raptors. OneRain removed the standpipe from this site and replaced it with a "traffic control" style structure. The tipping bucket is a "Peter Ward" style gage with a vertical screen. This screen will enable debris to collect in the bottom of the funnel while still providing a path for water to flow into the measurement mechanism.

Heavy equipment operators near the Cub Creek below Blue site damaged the standpipe. The body of the structure was dented enough to prevent removal of the transmitter. OneRain's technicians were able to force the standpipe open enough to remove the transmitter, but it had to be replaced. The new standpipe allowed the tipping bucket to be leveled properly, and restored access to the transmitter and PT.

The Sports Complex (Sportsplex) site was reinstalled once the construction work to rebuild the channel of Van Bibber Creek was complete. The site was completed on September 13th. This is a combined rain and stage measurement site.

The Tollgate at 6th Avenue site has been functioning well over the past several years, but, as the channel has scoured, the stage sensor was not able to measure low flow. To address this OneRain replaced the PT with a bubbler-type sensor. The bubbler is housed in a structure owned by the USGS which is adjacent to the standpipe. The bubbler tube runs through the original PT conduit and into the stilling pipe adjacent to the stream. The orifice was installed in conduit that makes a 90° downstream bend. This helps to make sure that silt and other debris do not collect in the tubing. Also, the bubbler has a 5-minute purge cycle that will prevent water from freezing in the tube which would cause erroneous measurements.

Construction activities near the Croke / Westwoods site damaged the PT riser at this site. OneRain replaced the riser and adjoining conduit as well at the PT itself.

Holly Dam suffered a nearly direct lightning strike. All of the electronics were destroyed, even the temper of the metal in the antenna changed as a result of the strike. OneRain replaced the transmitter, antenna, and signal conditioning box. The PT was replaced with an integral sensor and lightning arrestor. This device comes with a warranty against damage due to nearby lightning strikes. A direct hit is not covered under the warranty, however.

Removals Requested Prior to Construction Activity

A holdover from 2004, the Castle Oaks site (2830) reinstallation is still pending.

PT Failures/Replacements

Overall PT failures were average for the 2006 field season as compared to previous years. Fourteen (14) PT were replaced this year, and four (4) replacements were due to damage or relocation.

- Ralston Reservoir (site 110) damaged, Druck PT, having been in service for 1 year, 7 months.
- Croke / Westwoods (site 120) damaged, having been in service for 1 year, 11 months. The sensor was salvaged with 60 feet of cable.
- Sports Complex (site 320) relocated, having been in service for 6 years. The sensor was salvaged with 30 feet of cable.
- Kelly Dam (site 410) Druck PT, failed after 7 months of service.
- Harvard Gulch Park (site 600) Druck PT, failed after having been in service for 3 years, 10 months.
- Iliff Pond (site 650) Druck PT, failed after 1 year, 8 months.
- Maple Grove Reservoir (site 1000) Druck PT, failed after 3 years.
- Gunbarrel (site 1100) Keller, failed after 14+ years.
- DIA at 3rd Creek (site 1480) Druck PT, failed after 4 years, 1 month. This sensor was replaced on December 29th, 2005.
- Powers Park (site 1500) Druck PT, failed after 3 years, 2 months.
- Holly Dam (site 1610) Druck PT, struck by lightning after 4 years of service. OneRain replaced this unit with a lightning protected sensor made by KPSI.
- Sand Creek Park (site 1800) Druck PT, failed after 11 months of service. The previous PT at this site only lasted only three weeks longer.
- Cub Creek below Blue (site 2270) Keller, failed after 14 years of service. This PT was not visibly damaged by the construction activities that dented the standpipe.
- James Creek (site 4440) Druck PT, failed after 9 years of service.

Miscellaneous Activity of Note

Handar 555F Transmitters and 425A Sonic Wind Sensors

The Handar 555F weather station transmitters were installed between 1994 and 2000. These units have generally been reliable, but recently there have been repeated issues with the 425A sonic wind sensors. Communication with Vaisala, the owner of both the 555F and sonic wind sensor technology, has not resulted in a solution. The Vaisala technical representatives have looked through logged data that OneRain collected on their request and they have acknowledged the problem, but have not been able to provide a fix. The most notorious offender has been Squaw Mountain. The station repeatedly sends peak wind speed values of 181 miles per hour. This is obviously in error. When the same sensor in connected to another transmitter (i.e., Campbell Scientific CR10X) these errors are eliminated.

OneRain's tests have produced consistent results, and we have failed to reject the hypothesis that the 555F model transmitter is incorrectly reading the sonic wind sensor's values. Therefore, we recommend replacing these transmitter units at all sites with a sonic wind sensor. There are two (2) such units in the field today: Squaw Mountain (site 2190) and Elbert (site 1440). These transmitters were installed in 2000 and 1998 respectively.

Handar 585 Transmitter Replacement

The UDFCD system includes 17 sites (not including Quincy Reservoir) that are in excess of 14 years old. These Handar 585 units are no longer supported by any manufacturer. Table 1 summarizes the older sites.

Table 1, UDFCD Sites with Equipment Older than 14 Years

Site ID	Site Name	Sensors*	Model	Purchase Date
130	Simms Street	S	585 B Rev G	1/1/1990
150	Knott Creek	P	585 B Rev G	1/1/1990
330	Van Bibber @ 93	PS	585 B Rev G	1/1/1990
750	Quincy Reservoir	PW	585 B Rev G	1/1/1991
1110	Gunbarrel	PS	585 B Rev G	1/1/1991
1630	S Platte @ Dart	E	585 C Rev G	1/1/1990
1720	Cherry Cr @ Steele	PS	585 B Rev G	1/1/1991
2230	Bear Creek @ Cub	PS	585 B Rev G	1/1/1991
2240	Cold Spring Gulch	PS	585 B Rev G	1/1/1991
2250	Rosedale	PS	585 B	1/1/1990
2260	Brook Forest	P	585 B Rev G	1/1/1991
2270	Cub Ck below Blue	PS	585 B Rev G	1/1/1991
2280	Kinney Peak	P	585 B Rev G	1/1/1991
2310	Genesee Village	P	585 B Rev J	1/1/1991
2350	Idledale	P	585 B	1/1/1991
2360	Indian Hills	P	585 B Rev G	1/1/1991
2370	Red Rocks	PS	585 B Rev G	1/1/1991

*PW = rain and weather array, E = shaft encoder, PS = rain and stage, P = rain

Since the enclosures ("cans") and attached connectors for all of these units are still in good condition, OneRain could replace the transmitter, controller and datalogger components with up-to-date hardware. This can be done for a lower overall cost than completely replacing 585 with new off-the-shelf units. OneRain recommends using the following major hardware components for this task:

- Midland (formerly Maxon) RF transceiver
- Blue Water Design CommEngine (ALERT controller), this device also handles all rain and battery reporting
- Campbell Scientific CR200 datalogger, for sites with pressure transducer and shaft encoder devices
- Campbell Scientific CR1000, for weather station sites

The advantage of this method is that programmable datalogger functionality is added only to those sites that need it. For the five rain-only sites a CommEngine and radio will suffice.

Tipping Bucket Replacement

During the 2006 season the District had 12 of the old-style, soldered tipping buckets in the field. These rain sensors are easily damaged if accumulated water freezes in the bucket which can certainly occur in the spring and fall. OneRain recommends that the District continue with the annual replacement schedule and upgrade all 12 of these units this year.

FCC Licensing

To date, OneRain has received confirmation for renewed or extended licensing on all sites and call signs.

Smoky Hill Repeater

This remains a priority for OneRain because the RF path between our receiver and this site has been marginal. The East Cherry Creek Water and Sanitation District owns the property where this repeater is located. They have expressed a strong desire to have this station moved as well.

FUTURE AREAS OF INTEREST

During the second half of 2005, the District initiated a monthly meeting between OneRain and UDFCD staff. During these meeting we discussed future direction for the system, current operational issues, and resolved any unfinished business items. This section covers some of the topics covered in those monthly meetings.

Lakewood Gulch

This stage site is currently under contract and will be installed before the end of 2006.

Lakewood Country Club

The District has secured a new rain gage site at the Lakewood Country Club. This installation is in process and should be executed during the 2007 season.

Brighton Weather Station Relocation

The District and OneRain have established a new location for this weather station and given the recommendation to City of Brighton staff. We require their input prior to completing this task.

East Plum Creek

This is a shared site with the USGS on Haskins Gulch. USGS technicians have replaced the sensor with a unit that is not compatible with our existing transmitter, and they have been very hesitant to make further changes. The sensor in place now is a Sutron Accububble bubbler gage with only SDI-12

and quadrature output. Since the input to the existing transmitter (High Sierra 3206) is 0 – 5 volts these two options are not acceptable. Rather than ask the USGS technicians to, again, change the configuration of this site we could "listen" to the SDI-12 data. This can be accomplished with an HSE 4015 signal converter. When the USGS datalogger polls the bubbler the converter adjusts the output so that the transmitter reads the proper value. This solution would be cost effective and the least intrusive from the USGS' perspective.

DATA ANALYSIS

This year OneRain and the District approached maintenance in a new way. By reducing the number of preventive maintenance visits we were able to reduce costs significantly. At the same time we applied new predictive maintenance techniques to improve our ability to explore the data from a maintenance perspective. Table 2 below summarizes the maintenance activity over the course of the past five years. The "Service Rate" column is the ratio (%) of service calls to sites in the combined UDFCD/Boulder system.

Table 2: Recent Maintenance Activity Statistics

Year	Total Visits	Service Calls (OneRain/District)	Number of Sites[1]	Service Rate
2001	701	66 (30/36)	152	43%
2002	723	59 (45/14)	161	37%
2003	794	110 (86/24)	171	64%
2004	790	78 (51/27)	173	45%
2005	810	97 (76/21)	174	56%
2006	696	97 (78/19)	182	53%

The general trend over the past five years has been increasing service rate. 2003 was an exceptional year with almost as many breakdown maintenance visits as there were sites in the system. This year we reduced the number of scheduled maintenance trips from five per site to four. We added eight (8) sites, which includes new installations as well as base stations, and had the same total number of breakdown visits as 2005. Despite spending less time at the site, OneRain was still able to identify site problems even without having to directly inspect the sensors.

These proactive techniques end up preventing issues from becoming problems. OneRain's data analysis techniques caught several batteries before they dropped out of service and identified sites with inappropriate reporting

[1] This total number of sites includes repeaters and base stations.

criteria. They also have caught problems that we didn't know the system had such as catching plugged tipping bucket rain gages and helped to significantly reduce the number of battery reports due to the lack of solar regulation (2400 reports per month reduction).

In addition to providing near-real time reports on sensor activity OneRain provided post-event analyses. These analyses indicated issues with both radio path reliability and clogged tipping bucket funnels. The following two graphics were included with the reports that were triggered by the criteria of 10 gages receiving at least one inch of rainfall in seven days.

Bottom line for this process: several gages were identified as clogged, others appeared to be misrepresenting rainfall but were really reporting properly. In all this has helped all of us to increase our confidence in the performance of these gages. We are, however, at or beyond channel capacity with many lost rainfall reports. As the table below indicates there have been reliability issues with marginal radio path. The Englewood Dam sensor (76%) is not included in this last because we are attributing the low reliability to a failed radio and not radio path issues.

Table 3: Rain Sensor Availability (< 85%) for the 2006 Season

Sensor ID	Name	Availability
860	Sand Creek @ Colfax Rain	59%
2270	Cub Creek Rain	65%
4820	Dowdy Draw Rain	74%
1720	Cherry Ck/Steele Rain	76%
540	Parker/Miss Rain	78%
1710	Shop Creek Rain	81%
2340	El Rancho Rain	81%
110	Ralston Res Rain	82%
4850	Porphyry Mtn Rain	82%
410	Kelly Dam Rain	82%
2250	Rosedale Rain	83%
2190	Squaw Mtn Rain	83%
1440	Elbert Rain	83%
1330	Roslyn Rain	83%
850	Flying J Rain	84%
730	NoName/Quincy Rain	84%
310	Guy Hill Rain	84%
630	Temple Pond Rain	84%
4830	SBC @ San Souci Rain	84%

OneRain has recently added two of the sites in the above table into the Louisville repeater's pass list. These are SBC @ San Souci (4830) and Dowdy Draw (4820). Additionally, the Shanahan Ridge (4810, 86%) and SBC Ditch (4840, 88%) sites have been added to the Louisville pass list. This should improve the reliability of these sites.

In addition to analyzing each gage individually to evaluate it's RF performance OneRain compared gages to each other (nearest neighbor analysis), and qualitatively compared the gages to radar data (unadjusted radar rainfall analysis). The graphics below show the results of the radar rainfall comparison.

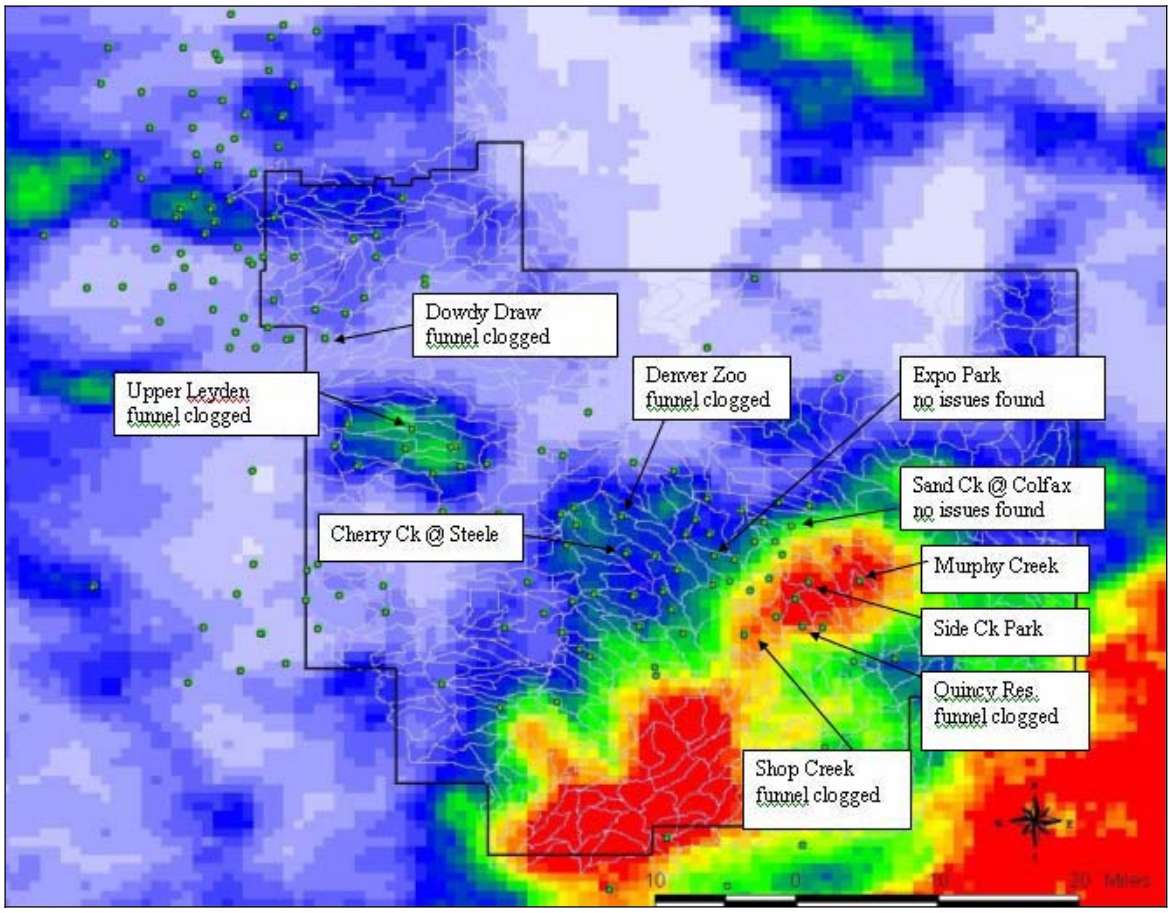

Table 4: Unadjusted Radar Rainfall Accumulation 7/7/2006 – 7/10/2006

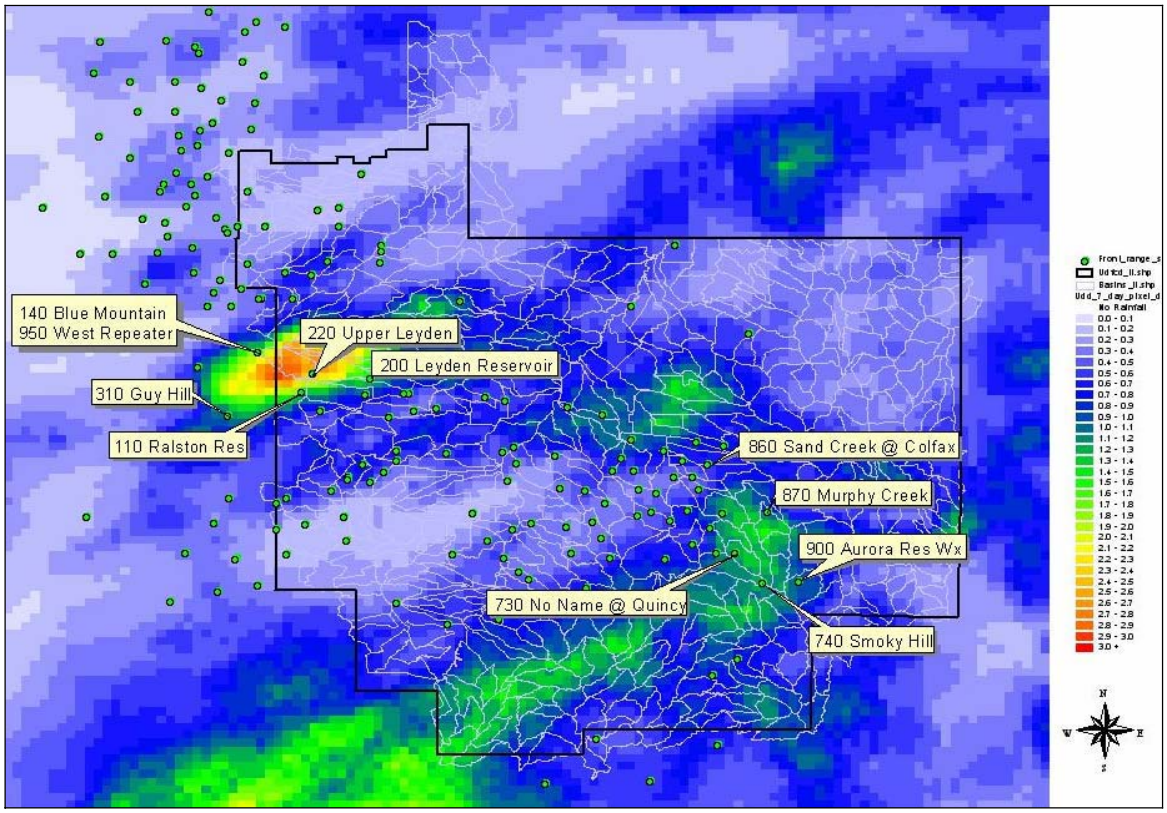

Figure 2: Unadjusted Radar Rainfall Accumulation 8/1/2006 – 8/3/2006

The radar rainfall to gage comparison provided a means to qualify a gage if it was flagged as part of the nearest neighbor analysis. For example, even though the Expo Park gage was flagged as under reporting as compared to its neighbors in the July analysis it is easy to see in the graphic that not as much rain fell at that location. On site inspection did not reveal any debris or calibration issues that would have contributed to under-reporting.

There are still failure modes that cannot be found without direct calibration, measurement, or inspection. The challenge to optimizing maintenance is to find the minimum number of preventive maintenance visits while still catching problems. This year's activities have come closer to achieving that goal.

CONCLUSION

This was a very successful in both reducing costs and improving performance. This report has not addressed the very serious RF channel contention issues. Aside from these problems the combined UDFCD / Boulder County flood detection system has performed well with no significant event going undetected. As compared to 2005 there were a high number of PT failures (10 versus 5) and the same number of radio failures this year (5 versus 5). The positive aspect of this is that these problems were caught by preventive maintenance.

Further challenges include improving methods to calibrate and validate weather sensor data, establishing statistics on the useful life of a piece of equipment, improving the detection rate of site and sensor failures, and addressing issues of traffic contention.

APPENDIX A: EQUIPMENT RECOMMENDATIONS

The items listed below are in order according to OneRain's recommendation of priority:

1. Spare Radios.
   - Due to nearby lightning strikes and non-warranty component failures, the UDFCD system lost five radios during the course of this year. The unit price listed below is with the distributor's discount.
   - Total Price: 5 x $237 = $1,185

2. Pressure Transducer Replacements and Spares.
   - All of the below listed PTs would be ordered from GE Druck. OneRain experienced troubling quality issues and poor customer service during the 2004 and 2005 seasons. For this reason we switched to KPSI/Esterline units with lightning protection in 2006. The size of these units made installation difficult in many areas. Since the Druck PTs have been performing better we will balance the need for lightning surge protected devices from KPSI with the need for smaller transducers this year.
   - 160, 1 x $1,270 (Druck 100 mV)
   - 100, 1 x $1,195 (Druck 100 mV)
   - Total Price: $2,465

3. Signal Conditioning Modules.
   - Some have been damaged by voltage surges and others are for interfacing with upgraded transmitters.
   - High Sierra Electronics 100mV to analog signal conditioning modules, five (5): 5 x $100 = $500
   - Total Price: $500

4. Transmitter Spares.
   - 3 High Sierra Electronics 3206 ALERT transmitter
   - One for replacement of the non-narrow band Sierra-Misco 5050 at Magnolia.
   - Two additional units bring the spares for this transmitter type to 10%.
   - Total Price: 3 x $2,706 = $8,118

5. Handar 555F Replacements.
   - Replacement will retain the original enclosure and will include a new FCC-compliant radio, Blue Water Design transmitter controller (CommEngine) and, where sensors other than rain are required, a Campbell Scientific CR1000 datalogger.
   - The three sites where the 555F is connected to a Vaisala sonic wind sensor: Blue Mountain, Squaw Mountain and Elbert.
   - Three (3) weather station transmitters = 3 x $3,823 = $11,469
6. Total Price: $11,469.

7. Handar 585 Replacements.
   - Replacement will retain the original enclosure and will include a new FCC-compliant radio, Blue Water Design transmitter controller (CommEngine) and, where sensors other than rain are required, a Campbell Scientific datalogger. This datalogger will make integration with the existing 4 – 20 mA PT's very simple.
   - Since these platforms are among the oldest in the system and have been subject to wear and tear for nearly 15 years, they are more likely to fail than their younger counterparts. Direct replacement by spare equipment is not practical because the connectors are different.
   - OneRain does not recommend replacing the weather station at Quincy at this time.
   - Since funds are limited we would recommend starting with the rain only sites, as these would provide the greatest cost savings.
   - 6 Rain-only = 6 x $1,907 = $11,442
   - 10 Rain and stage (encoder or PT) = 10 x $2,482 = $24,820
   - Total Price: $36,262

8. Relative Humidity and Air Temperature Sensor Replacement.
   - The majority of the RH/AT sensors in the system are still supported by the original manufacturers (Vaisala [Handar], and HydroLynx).
   - There are eight Sierra-Misco sensors in the system that are over seven years old, and cannot be calibrated.
   - Total Price: 8 x $1,165 = $9,320

9. Wind Sensor Replacements.

- The cup-anemometer wind sensor at Calwood is damaged and should be replaced. HydroLynx 5050-WS = $200.
- The UDFCD system has 9 sites with this type of anemometer. OneRain recommends keeping a spare set, 5050-WS and 5050-WD, on hand as a spare. 5050-WS + 5050-WD = $200 + $200 = $400.
- Total Price: $600.

10. Tipping Bucket Replacements.
    - Only 12 of the soldered-style tipping buckets remain in the system.
    - Total Price: 12 x $306 = $3,672

11. Solar Panel Replacements.
    - This year OneRain replaced the solar panel at DIA @ Third Creek, Lake Shore, and Twin Sisters. There are many others that have been in the field for over 10 years.
    - Total Price: 5 x $132 = $660